DISCUSSION BEFORE THE WIRELESS SECTION, 7TH MARCH, 1928.

Col. A. S. Angwin: The paper deals more particularly with the application of quartz resonators for precision measurement, in which constancy of frequency is of greater importance than a large output from the crystal. One apparent point of divergence between the two applications is in the method of mounting the crystal. As the authors point out, for large power output an air-gap gives the best results, but if maximum output is attempted there is a tendency for sparking and consequent instability to occur. By reducing the air-gap a point is reached at which it is possible to get quite a large output, but something less than the maximum. For these reasons the type of mounting which the Post Office has found to be most suitable for controlling valve generators is one employing a metal-to-metal contact, with a micrometer adjustment for varying the pressure contact. With this method of mounting it is possible to obtain an 80-watt output from a single valve with a crystal between grid and filament, and with a frequency of 3 000 kilocycles. With the circuit arrangement which the authors show in Fig. 14, I notice that three stages are employed to obtain a somewhat similar output with a frequency of 240 kilocycles. The possible explanation is the difference in the frequencies concerned. It would, I think, be of interest to know whether the additional stages in this arrangement are necessary owing to the lower frequency used. With regard to the statement on page 857 and also in the conclusion which the authors draw as to the relative constancies of elinvar forks and quartz resonators, I am not quite sure whether the authors are not a little conservative in their estimate of the possibilities of the quartz oscillator as a frequency standard. In the last number of the *Proceedings of the Institute of Radio Engineers* (1928, vol. 16, p. 137) a description is given of a quartz-controlled oscillator constructed in the Bell Telephone Laboratories which has maintained a constancy of frequency of the order of 1 part in a million tested over a period of about 10 days. That seems to be an order of accuracy which is at least as good as that given by any elinvar fork. Of course it is appreciated that in order to get that constancy of frequency with the quartz oscillator it is essential that it should be maintained under fairly constant temperature, but that is not very difficult to ensure, and I think that on the whole the conclusions of the paper indicate that there is a great possibility in the use of the quartz resonator for obtaining orders of accuracy which are at least comparable with that obtained from the elinvar fork. The authors use the term " multi-vibrator " in the arrangement shown in Fig. 20. I think the generally accepted use of that term is that first evolved by Abraham and Bloch in which the circuit used is not really an oscillatory circuit at all, but the periodicity of operation is dependent upon the capacities and resistance, and possibly the arrangement described by the authors might be more correctly referred to in the more general terms of " crystal-controlled harmonic generator " as distinct from the particular form known as the " multi-vibrator." Another point on nomenclature arises. On page 162 the authors speak of " longitudinal resonators in which the length is several times as great as either of the other dimensions." There is possibly some little uncertainty there as to the meaning of the phrase " longitudinal resonator." In Cady's paper, to which the authors refer, such oscillators are described as transverse oscillators, the distinction being that longitudinal oscillators are defined as those in which oscillation takes place in the direction of the applied electric field, and transverse oscillators those in which the oscillation takes place perpendicular to the applied electric field. On page 159 there is possibly a misprint. In speaking of the quartz oscillator the authors say: " The wave-length of each crystal has been accurately measured, and a calibration chart is provided with the instrument, giving the fundamental wave-lengths and

also all the harmonic derivatives, between 100 and 4 800 m, to be obtained therefrom." I think it is possible that 4 800 should read 1 800, being one of the fundamentals and not a harmonic derivative. If it is not so, I am not quite clear as to how the figure 4 800 is derived.

Lieut.-Col. C. J. Aston : In the part of the paper dealing with their experimental work, the authors give some figures showing the variations in frequency caused by changes of temperature, air-gap and circuit conditions. These figures suggest means whereby the frequency of a quartz oscillator may be deliberately adjusted to a very fine degree of accuracy, more easily perhaps than by fine grinding. In certain circumstances it is desirable to adjust the wave frequency of each of a group of wireless stations to almost exactly the same value, so as to enable a receiver to keep watch for several transmitters without searching. Also, the use of a very constant oscillator the frequency of which can be varied within fine limits is needed if superheterodyne methods of reception are desired. A quartz crystal may have advantages for this application. The process of grinding quartz crystals becomes progressively more difficult and consequently more expensive the smaller the tolerance in frequency the maker is allowed. By making use of such variations as can be produced by temperature-changes, etc., it may be possible to match the frequency of a number of crystals very closely without resorting to the expensive process of accurate grinding. In cases where accurate *maintenance* of frequency is necessary, some form of thermostatic control seems to be essential in order to eliminate the effects of ordinary atmospheric temperature-changes. It should not be difficult to adjust the temperature until the desired frequency is accurately obtained, and then to set the thermostat to maintain that temperature. Quartz-crystal makers can measure frequency to an accuracy of 1 part in 1 000 with ordinary resonance wavemeters, but to get a finer degree of accuracy expensive apparatus is needed. With quartz having a variation of 30 parts per million per 1 deg. F., a variation of 33 deg. F. will suffice to produce a change of 1 part in 1 000. It may therefore be possible to allow makers a tolerance of 1 in 1 000 in cases where temperature control can be applied to the crystal oscillator. The authors have, to my knowledge, tested some 10 specimens of quartz between about 60° F. and about 120° F., between which limits the variation of frequency with temperature has followed a straight-line law. It therefore appears that most quartz has practically a straight-line frequency coefficient. Nevertheless it is interesting to note that in one specimen tested there were three sudden jumps of frequency at well-defined points within these limits; the quartz produced a very effective oscillation at about 60° F., this becoming less and less effective as 80° F. was approached, when a sudden change of several hundred cycles in frequency took place, accompanied by effective oscillation again at the new frequency. A similar phenomenon occurred at about 100° F. This effect has not yet been investigated and may have been due to a defective piece of quartz, but it may serve as a warning that care may be needed if temperature control is to be utilized. The authors also make reference to variations in frequency of a quartz resonator caused by varying the air-gap between the electrodes or the capacity in series with the crystal, and this appears to be another way of adjusting the frequency of an oscillator to an accurate value. It has been found, however, that in the case of the air-gap there is an optimum spacing at which oscillation is greatest; this phenomenon may be due to the influence of waves in the air in contact with the vibrating quartz which have a damping effect on its mechanical oscillations. In practice we have found that for oscillator circuits it is perhaps best to use no gap at all. On page 151 the authors refer to the proposed use of quartz crystals as selective couplings between valve stages and as rejectors. These proposals are interesting. A short test made at Woolwich of the former seemed to indicate that the damping of a quartz crystal may be so small as to cause it to act somewhat as a band-pass filter too narrow to allow speech to pass. Possibly there may be means of increasing and controlling the logarithmic decrement—I do not know. If there is any method of controlling the logarithmic decrement (for instance by increasing the electrode pressure) I suggest that a quartz crystal might be usefully employed as a band-pass filter.

Mr. H. J. Lucas: The authors have apparently utilized very freely the longitudinal mode of vibration for the purposes of control. This is contrary to the usual practice, as control can be much more easily obtained from the transverse mode of vibration. Have the authors obtained oscillations with the longitudinal mode in the circuits shown in Figs. 4 and 5? In all the other circuits some form of extraneous reaction is used. In view of the fact that the crystal is very liable to exercise control on frequencies other than the fundamental, the use of reaction in control circuits is generally to be discouraged. In fact no guarantee can be given that the set will start up on any predetermined frequency. This may not apply to longitudinal vibration, for as a rule the fundamental is very marked, with no vibration of the same order near the fundamental period. In the case of transverse vibration, one frequently finds quite a number of periods round the main fundamental of approximately the same amplitude as the fundamental, and with reaction it is a matter of chance as to which of these exercises control. I should like to point out that a neon-tube wavemeter exactly similar to that referred to on page 861 has been in use since 1924. This may or may not anticipate the authors' instrument. I am particularly interested in the authors' work in the use of the crystal as a fundamental frequency standard. Personal experience has shown that a quartz resonator used as a frequency standard by means of the Cady crevasse method has an accuracy not greater than 1 part in 3 000, and within these limits it is extremely unstable both with regard to frequency and logarithmic-decrement changes, these changes being introduced by a mere tap of the crystal-holder. With these limitations it is obviously no competitor of the elinvar tuning-fork. Investigations showed that these inaccuracies were due to three causes, and when these were eliminated a standard was produced which was at least as useful and accurate as the elinvar tuning-fork. The principal cause of these errors was found to be variable frictional loading. This was eliminated by firmly

supporting the crystal at a nodal zone of displacement. This accounted for the major portion of the previously noted errors. Further errors are caused by variable dielectric losses due to atmospheric humidity. If the crystal is breathed upon, it ceases to oscillate. The third cause of error is air loading. The two latter were met by desiccating agents, and finally by evacuation. The final product was a frequency standard which could be adjusted to within 1 part in 10 000. Owing to the considerable improvement in decrement obtained and the complete stability of the standard, its period can be determined to within 1 part in a million for a resonator with a period of 100 kilocycles. Further, they can be constructed at a relatively low cost for any convenient point in the frequency spectrum used by the high-frequency engineer. The temperature coefficient is of the order of 1 part in a million per 1 deg. C., and hence is negligible under working conditions of the laboratory. For these reasons this type of crystal has proved more useful than the elinvar tuning-fork. It must be emphasized that this comparison applies only when the two pieces of apparatus are considered as fundamental standards under no-load conditions—the only fair comparison of such standards. The considerable improvement in the decrement obtained by the method enables the crystal to be used in the longitudinal mode of vibration with air-gaps of the order of 1 mm for control purposes. In these circumstances the generated frequency has a value within 1 part in 10 000 of the natural period of the crystal.

Mr. T. G. Hodgkinson: Have the authors measured for any of their crystals the electro-physical constant B referred to on page 153? A point raised by Col. Angwin and noted by Mr. Lucas appeals to me as important, and that is the necessity for clearing up the question of nomenclature for the different modes of vibration of piezo-electric crystals. In the literature of the vibrations of bars the transverse modes are the bending modes, and I think that this meaning should be adhered to. Normally, I take it, the true transverse or bending modes are not maintained in oscillation, but possibly with an asymmetrical distribution of the applied electric field they might be excited. The overtones of bars vibrating in the longitudinal mode are harmonic to the fundamental. Is it possible to make a crystal support oscillation at the frequency of its harmonics? If this could be done the design of short-wave oscillators would be simplified to some extent.

Mr. S. J. Underhill: I think it is important that it should be decided very soon which is the longitudinal and which the transverse vibration. It has been suggested that the longitudinal vibration is the vibration perpendicular to the direction of the electric field, but I think that Cady used the opposite notation. Some ruling on this point should be made and adhered to in order that there may be no confusion in the future. Mr. Lucas has raised the question of the mounting of oscillators and resonators: that is a very important point, and one that should always be taken into consideration. I can confirm his statement that breathing upon the crystal will cause it to stop oscillating. The material used for the mount must be of the very best quality, and the mount should be carefully designed, especially so in the case of a dust-proof mount which totally encloses the crystal. If poor material is used, or if the mounting is badly designed, the efficiency falls off considerably. The question has been raised as to whether any work has been done with crystals in which steps have been cut. I would say that such crystals have been made; indeed, in making crystals for a frequency of more than 3×10^6 cycles it is not easy to grind them to the requisite accuracy to avoid two frequencies being generated simultaneously, even when the quartz is pure. When the quartz is impure the crystal very frequently "sings," as one part of the crystal is oscillating at one frequency and another part of the crystal, of equal mechanical thickness, is oscillating at another frequency, but not at such a different frequency that the beat note between the two is outside the audio-frequency range. When the beat note is outside the audio-frequency range nothing is heard, but the defect makes itself manifest, in that the control is unstable and tends to jump from one frequency to another as the circuit conditions are altered.

Prof. J. T. MacGregor-Morris: In Table 1 there is a set of measurements giving the connection between frequency of oscillations and the length of the air-gap in series with the crystal. What evidence have the authors that the constancy of the frequency of oscillation is reliable when there is no air-gap? Those of us who are interested in measuring resistances of samples of insulators and who have to make measurements of those insulation resistances with direct current and also with alternating current know the great difficulty there is in getting a really good contact between the specimen and the electrode. Dr. Dye has found with certain insulators for permittivity measurements that it is much better to make the measurement with a definite air-gap than to attempt to avoid the air-gap altogether. I very much doubt whether the air-gap is ever got rid of, and so I should like to ask what methods are employed when attempting to get the electrodes into real contact with the quartz. Alternating-current measurements of capacity and resistance show that there is a definite capacity and a definite resistance at that contact. Therefore I do not think that Fig. 3, in which a condenser C_3 is in series between Y and Z, is a complete statement. That condenser should at least have a resistance in parallel with it to simulate the behaviour of one of these gaps. I think that a searching test would be to remove a crystal from the electrodes and discover how nearly the frequency can be repeated when the crystal is replaced. From Table 1 it will be seen that when the gap is reduced from 1 mm down to 0·1 mm the change in frequency caused by a change of air-gap of 0·01 mm varies as follows:—

1·0 mm air-gap	1 cycle per sec.	
0·5	,,	2 ,,
0·1	,,	7 ,,

so that the rate of variation of frequency with small changes of air-gap increases very rapidly as the gap is reduced, and this suggests that uncertainty as to frequency would almost inevitably result when the air-gap is ostensibly, but not actually, reduced to nothing, for in such a case the two components would, of course, stick together.

Mr. E. B. Moullin : I should like the authors to say what considerations govern the size of their crystals in the two dimensions not principally concerned with the desired fundamental frequency. The limits of size and shape of their crystals are described in section (5) on page 151 and the size is much larger than I should have expected, having had no practical experience of their use. Section (10) implies to me that the mode contemplated is compared with the free longitudinal vibration of a long, thin bar, but the plates used have sides much larger than their thickness, which, I imagine, is the dimension regulated to give the required frequency. I am surprised that there is a reasonably constant relation between the thickness and the wave-length of the electrical vibration generated; I should have expected that it would also have depended on the length of a side of the plate. An elongation in one direction is always accompanied by a contraction in the two mutually perpendicular dimensions, of an amount depending on Poisson's ratio for the material. The motions due to these sideways contractions will possess kinetic energy, which I should have thought would greatly have modified the fundamental frequency. The longitudinal motion accumulates with the length of the rod, while the sideways contraction does not, and hence the longer the rod the less important becomes the lateral inertia. For this reason I should have thought it advisable to make the shape of the crystals approximate more closely to that of a long rod. It may be that the mechanical difficulties of grinding require that the surface area of the crystal shall be not smaller than those used, or again it may be that the required vigour of response prohibits the volume of the crystal from being less than some definite amount. I should like to know whether the two dimensions which do not mainly determine the frequency are chosen for either of the two reasons I have just stated or whether they have been adopted fortuitously.

Captain P. P. Eckersley : The more and more accurate establishment of frequency standards is extremely important. Some years ago accuracies of 1 per cent or 2 per cent were sufficient for ordinary stations. To-day, particularly in the field of broadcasting, accuracies of the order of 1 in 10 000 are desirable if mutual interference between stations is to be avoided. The authors mention comparative tests as between tuning-forks and crystal for maintaining a frequency standard. They also mention that certain American stations use a crystal drive for maintaining an absolute frequency standard. In my opinion both the crystal and the tuning-fork are useful in maintaining standards for measurement. Neither the tuning-fork nor the crystal is necessary, except in exceptional cases, for actually " driving " and thus maintaining constant frequency at transmitting stations. For instance, by using the drive and separator at 5GB it has been established that variations of not more than 100 cycles in 600 000 cycles take place. It is, however, essential to have some standard wavemeter both at the broadcasting station and at some central point which is able continuously to check the accuracy of the wavemeter in the station. The method successfully adopted for broadcasting stations in Europe has been to equip a control centre at Brussels, which even at great distances is able to check the wave-length of stations using sub-standard wavemeters. The method adopted at the control centre at Brussels is interesting and has some bearing on the authors' work in connection with crystals, inasmuch as it was found necessary in the interests of accuracy to rely mainly upon the tuning-fork to do cross checks with crystals. The method of working is extremely simple, involving a heterodyne wavemeter which is made to beat at a certain frequency with the carrier wave of the station to be measured. This frequency is made coincident by zero beat method with a tuning-fork. The heterodyne wavemeter is then read. The condenser of the wavemeter is then changed so as to beat on the other side of the resonance curve. This beat is made also coincident with the tuning-fork of the distant station, and the wavemeter is read. The midway point between the two readings gives the frequency of the station. The heterodyne wavemeter is continually checked by a standard tuning-fork and multi-vibrator. This tuning-fork has an accuracy of 1 part in 100 000 and was calibrated at the National Physical Laboratory. By this means a 1-kW station 1 000 miles distant from the control centre is able to be measured with an accuracy of at least 200 cycles in a million. Calibrated crystals have been used further to check wavemeters, but they have not been relied upon as standards. The work of establishing the wavemeter in Brussels and the methods adopted for its calibration have been due to M. Divoire of the University of Brussels.

Mr. B. Williams : The experience of the Royal Air Force with quartz resonators and oscillators for radio-frequency work dates back to 1923, when Prof. Cady visited Farnborough and demonstrated the remarkable properties of quartz crystals. The response frequency of a special crystal, which was also measured at the N.P.L. and subsequently at standards laboratories in Italy and Austria, was measured—the object being a comparison of radio-frequency standards in America and Europe. Subsequently various adjuncts to wavemeters were devised and there has been in operation at the Air Ministry Station at Kidbrooke for some years a neon-lamp wavemeter on the lines of that described in the paper, with the difference that the crystals were ground down to the definite wave-lengths allotted to the transmitter, and the latter set on its wave-length by means of the " crevasse " method described. Developments in quartz oscillators of the types shown in Figs. 4 and 5 were retarded owing to the difficulty of obtaining good-quality quartz, and unsuitable cutting and grinding. The circuit of Fig. 6 was evolved for the production of laboratory standards of frequency. The minute variations of frequency due to variation of condenser C and air-gap were studied, and the final adjustment of frequency was made not by grinding but by adjustment of either of these factors. Some work was done on the use of quartz for high-frequency couplings, and a highly selective amplifier for a definite frequency was produced. The very low damping restricted the keying speed at the frequency used (about 100 kilocycles) to not more than 10 words per min. The selectivity was such that it was possible to operate a relay by a change in transmitter frequency of 1 part in 10 000. Later work has been in connection with quartz oscillators of the type shown in Figs. 4 and 5 with crystals cut in a specia manner and

operating on a fundamental frequency of about 4 000 kilocycles.

Mr. M. G. Scroggie: I should like to ask the authors whether, in studying the behaviour of quartz oscillators with an air-gap, they observed any variations in equivalent electrical properties of the crystal due to supersonic air waves set up in the air-gap space. The arrangement seems analogous to that of the air column in a loud-speaker horn which acts as a load on the diaphragm and can be expressed in equivalent electrical quantities. If the length of the horn is varied when the diaphragm is vibrated at a fixed frequency, the load due to the air column varies periodically as resonance points are passed through. One would expect something of the same sort to occur with quartz oscillators when the air in the gap resonates to the frequency of the quartz vibrations.

Mr. C. W. Goyder (*communicated*): The authors have employed the longitudinal mode of vibration of the crystal throughout. There would seem to be several points of difference between the operation of crystals as longitudinal oscillators and transverse oscillators. The most evident is the use of electromagnetic reaction between the plate and grid circuits of the crystal oscillator in the former case, as shown in the paper. It is generally accepted that such reaction in crystal oscillators employing the transverse mode of vibration is inadvisable and, in fact, quite unnecessary for crystals of good quality. The use of reaction in this case may cause several oscillation frequencies in the vicinity of the fundamental, serious frequency-changes due to the rapid variation of damping effected by any feed-back from following amplifiers, and mechanical fracture of the crystal due to excessive voltages. The several oscillation frequencies may be explained by the great difference in area of the active vibration surface in the cases of longitudinal and transverse vibration of the crystal. For the former case, used by the authors, the vibration surface is roughly 5 mm by 1·5 mm, a small area which will move as a whole. In the case of the transverse oscillator, the crystal is generally 1 in. square, the active surface is very much greater and there is no reason to suppose that it will always move as a whole. Owing to the varying thickness, or imperfect quality of the quartz, various areas of the crystal may oscillate independently at slightly different frequencies. Reaction, by reducing the overall damping, will assist other less prominent frequencies besides the fundamental to be maintained simultaneously. It would therefore appear that, for frequency standards, quartz crystals employing the longitudinal mode of vibration would be more reliable. A fault common to the majority of crystal oscillator circuits (such as that shown in Fig. 5) is that the oscillation amplitude of the crystal is not under control. To obtain maximum power output it is desirable to work without grid current and to employ a high voltage on the plate to furnish sufficient grid base. There is, however, no simple method of adjusting the oscillation amplitude of the crystal to conform to the required conditions. In practice, the oscillation builds up until grid-current damping or saturation limits the output. In one case where a high-quality 90-m crystal was connected in the circuit shown in Fig. 5, but using a fixed grid bias, the voltage generated by the crystal varied from 150 to 250 volts, depending upon the plate voltage. The resultant voltage in the plate circuit was hardly greater than this, indicating considerable over-excitation of the grid. Solutions of this difficulty are partial neutralization of the circuit, added resistance in the plate lead, etc. When such damping is employed the plate circuit may be tuned more accurately to the resonant frequency of the crystal, and hence a larger power output is obtained without danger of fracturing the crystal. That the plate circuit cannot be tuned exactly to resonance, but must be tuned to a frequency slightly above this in order to present the inductive reactance to the circuit required to maintain oscillation, is clearly shown in Fig. 11. I should be very interested to know whether the authors have compared the power output obtainable from crystals operating on high and low wave-lengths. It has been stated that the maximum power output obtainable from a crystal is on approximately 100 m.* The power output falls off as the wave-length increases, and the difficulty of obtaining ready oscillation increases. The repeated use of reaction in the oscillators shown in the paper would seem to corroborate this. In connection with the generation of audio-frequency beats by employing stepped crystals, this does occur only too often unintentionally in the case of crystals using the transverse mode of vibration, owing to the effects previously mentioned. In one instance a beat note was audible on rectification of the crystal output, and also a beat note of the same frequency coming directly from the crystal. Can this be attributed to interference between the two supersonic sound waves generated by the crystal, or to the electrostatic stresses on the crystal-holder? Although it is evident that crystals are not necessary for controlling the frequency of broadcasting stations under skilled control, surely their employment in the many European stations where this is not the case would be beneficial. One of the most useful applications of the crystal is in telegraphic stations operating throughout from an a.c. source without a rectifier, each stage consisting of two valves working alternately on each half of the a.c. cycle (the " self rectification circuit "). The independence of the crystal frequency with respect to voltage makes this possible. It is a method widely used by American commercial stations.

Mr. G. Shearing (*communicated*): Although the paper is confined mainly to the use of quartz crystals for the measurement of frequency, I think that their use for the control of transmitter frequency is of equal importance, and especially is this the case for short-wave transmitters. In this case the quartz crystal fulfils two important functions, for not only does it definitely limit the frequency to a narrow band determined by the actual variations of the quartz crystal and its associated air-gap, but, in addition, it prevents circuit frequency variations of a more transient nature which would otherwise occur with variations in filament and anode supply voltages. The multi-vibrator wavemeter is probably unsurpassed as a standard of reference, but the quartz resonator appears to fulfil the requirements as a sub-standard better than any other type of instrument. It is mainly in connection with the use of quartz crystals arranged as

* CROSSLEY: *Proceedings of the Institute of Radio Engineers*, 1927, vol. 15, p. 21.

transverse resonators for frequency stabilization of short-wave transmitters that I have had personal experience, for which purpose they have the advantage that their fundamental frequency may be such that only a small frequency step-up is required. The variation in temperature-coefficient values with geometry of the quartz are very great. The figures given emphasize the importance of temperature control at the higher frequencies of the order of 1 000 kilocycles. As regards the electrical circuit, a recent paper by Horton and Marrison * describes the use of a condenser shunting the crystal whereby electrical circuit-changes with temperature have no effect on the frequency. The crystal-holders described in Figs. 13 and 17 would appear to be such that considerable variations in the air-gap would occur with change of temperature, and better results might be obtained by the use of spacing arrangements such as that afforded by the use of invar or of fused silica as proposed by Dye,† whereby the air-gap can be kept constant with temperature variation. The circuit of Fig. 5 has been employed by Meissner ‡ for frequency control of transmitters, and he favours its use. My personal experience, however, is more in favour of the use of some retroaction, but in our case the reaction employed is insufficient of itself to start up oscillatory current. In this way good frequency control has been obtained for average crystals. We have, however, obtained excellent results with a relatively small proportion of crystals when using the circuit of Fig. 5. The authors do not refer to the matching of crystals to a given frequency value, and it is in this connection for short-wave transmitters that our greatest difficulties have been experienced. The question as to the best method of adjusting crystals to a definite frequency value is one on which I should like the authors to remark. In connection with grinding a crystal, we have observed the very great importance of having the two surfaces optically plane and parallel for good frequency control.

Messrs. G. W. N. Cobbold and A. E. Underdown (*in reply*) : With regard to the question of nomenclature raised by Col. Angwin and other speakers, it would appear to be unwise to classify resonators as " longitudinal " or " transverse," seeing that various modes of oscillation are possible in every case. Regarding these modes of oscillation we are in agreement with Capt. Hodgkinson when he maintains that the meanings which have been used in past literature on the vibrations of bars should be adhered to. This means, of course, that a longitudinal vibration results from the transverse piezo-electric effect, but as this is an accurate description of both the electrical and mechanical action there should be no objection to it. For those who wish to restrict the term " multi-vibrator " to the particular arrangement devised by Abraham and Bloch the use we have made of it will appear objectionable, but there is much to be said for the view that any harmonic generator, in which not one individual only but a group of harmonics are made use of, may be properly termed a " multi-vibrator " apart from distinctions as to the precise nature of the circuit used.

Regarding Fig. 14, the circuit was constructed during our early experiments and no attempt was made to obtain maximum power output from a single valve. There is reason to believe, however, that additional amplification is necessary for the lower frequencies if the risk of fracturing the crystals is to be avoided.

With regard to the harmonic derivatives referred to by Col. Angwin, the figure 4 800 is correct, the term " harmonic derivative," as distinct from " harmonic," having been used to cover both the case when B is a harmonic of A and when A is a harmonic of B. Thus the 4 800-metre point is obtained when its third harmonic beats with the fundamental frequency of the 1 600-metre crystal.

In reply to Mr. Lucas's inquiries, controlled oscillations with the longitudinal mode of vibration were not obtained in the case of the circuit shown in Fig. 4 when working with long bar crystals, but a certain degree of control was obtained with the circuit of Fig. 5. With regard to the use of reaction, we have not experienced any trouble as a result of this when using crystals on their longitudinal modes of vibration.

In reply to Mr. Hodgkinson, we have made no measurements of the electro-physical constant *B*. Attempts have been made to produce controlled oscillations at the frequencies of the harmonic of a crystal, but without success.

Prof. MacGregor-Morris's remarks regarding the difficulty of altogether getting rid of the air-gap are of great importance. We have no evidence that the frequency is constant when there is no deliberate air-gap ; in fact, in all our designs we have made use of as large an air-gap as possible. The addition of a resistance in parallel with C_3 in Fig. 3 would probably give a more accurate representation of the case when the deliberate use of an air-gap is avoided.

With regard to Mr. Moullin's inquiries, the area of cross-section of the crystal which is perpendicular to the dimension controlling the frequency must be large enough (1) to provide for the requisite amount of energy storage, and (2) to resist tendency to fracture under operating conditions. With a view to keeping down the cost, the area will not exceed what is required by these conditions by more than a reasonable margin of safety.

Captain Eckersley is to be congratulated on the high order of constancy maintained by the station 5GB, but it is evident from the jamming that occurs between certain Continental broadcasting stations that such accuracies are not maintained everywhere.

In reply to Mr. Scroggie, we have not experienced the variations in properties to which he refers in the case of bar crystals working on long wave-lengths ; and, regarding Mr. Goyder's query, we have not made any comparative measurements of power output from crystals over a wide band of wave-lengths.

Mr. Shearing's suggestion that fused silica or other material of low coefficient of expansion should be used for spacing-pieces between the electrodes would certainly lead to a higher order of accuracy being obtained, to the extent that this is dependent upon changes in the size of the air-gap. The matching of crystals, in so far as we have been concerned with the problem, has been carried out by careful grinding, but it would appear that the methods of adjustment proposed by Col. Aston would be valuable, particularly in cases where maximum power output is not demanded.

* *Proceedings of the Institute of Radio Engineers*, 1928, vol. 16, p. 137.
† *Proceedings of the Physical Society of London*, 1925–6, vol. 38, p. 447.
‡ *Proceedings of the Institute of Radio Engineers*, 1927, vol. 15, p. 281.